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THE AGRICULTURAL UTILIZATION OF ACID LANDS BY MEANS OF ACID-TOLERANT CROPS.

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INTRODUCTION.

In the past 20 years farmers have witnessed the development of what may be called a lime-and-clover literature and the growth of a corresponding agricultural practice. The scientific researches of various investigators published from 1867 to 1888 had demonstrated that leguminous plants through the bacteria of their root tubercles were able to take nitrogen from the atmosphere and that when a crop of these plants was plowed under the land was enriched as if by a corresponding application of manure.

In the northeastern United States the principal leguminous plant used in crop rotations had been red clover. The scientific confirmation of the popular belief that this plant had high value as a green manure greatly stimulated its use, the customary procedure being to plow under the clover turf after taking off one or two cuttings for hay. It was found, however, that if the land is acid in its chemical reaction red clover makes but feeble growth. If the chemical reaction is neutral or slightly alkaline and other conditions are favorable, heavy crops of red clover are produced. This consideration greatly extended the practice of applying lime, in order to neutralize the acidity of the soil and thus increase the manurial use of clover in crop rotations, over large areas of the older lands of the eastern United States.

It was found also that timothy, the chief hay grass of this region, was much longer lived and more productive in acid land when limed, and that wheat, one of the principal cereals, yielded much more heavily when treated in the same manner. Within the last few years the attempt in the acid East to cultivate alfalfa, the great hay crop of the alkaline West, has conveyed the same lesson in a still more striking manner, for alfalfa can not be grown satisfactorily in any soil, however fertile, which has an acid reaction. When grown

in the eastern United States alfalfa is not successful, except on calcareous soils, unless the natural acidity of the soil has been neutralized by suitable applications of lime.

One result of this advocacy of lime has been that in our anxiety to neutralize our acid soils and thus make them yield larger crops of such staples as clover, timothy, wheat, and alfalfa we have neglected to recognize clearly and to utilize the fact that some agricultural plants thrive as well in an acid soil as in an alkaline soil, or even better. It is proposed to discuss in this bulletin the bearing of soil acidity on agriculture and to direct attention to the utilization of part of our cheap acid lands through the development of rotations in which all the crops are acid tolerant, and the cost of making frequent and heavy applications of lime is therefore eliminated. These considerations are especially pertinent in sections where lime is expensive because of the remoteness of good commercial deposits of limestone. Where lime is not expensive the use of applications sufficiently heavy to neutralize the acidity of the soil is unquestionably profitable for many of the staple agricultural crops.

SOURCE OF SOIL ACIDITY.

One of the principal sources of soil acidity is decaying vegetation. The fallen leaves that carpet the floor of a forest are exceedingly acid. Freshly fallen leaves of some of our common trees show the following degrees of acidity, expressed in tons of ground limestone required per acre to neutralize a compact layer 6 inches in depth, estimated to weigh when dry 500,000 pounds, one-fourth as much as ordinary soil.[1]

TABLE I.—*Acidity of freshly fallen leaves, in terms of lime requirement per acre.*

Kind of leaves.	Acidity.	Kind of leaves.	Acidity.
	Tons.		*Tons.*
White oak	25	Sugar maple	22
Red oak	16	Tulip tree	14
Silver maple	22	Virginia pine	22

It is well known to farmers that on newly cleared timberland, not burned over, most crops do not grow well at first. A few, however, thrive in such situations, notably rye, buckwheat, and potatoes. All these are known to be acid tolerant. Table I, although representing conditions of acidity in excess of that actually existing in a cleared field, shows one of the sources of the acidity with which the plants have to contend and which is fatal to crops that are not acid tolerant. Another source of pronounced acidity in newly cleared timberlands is the freshly killed roots of the trees and underbrush.

[1] These acidity determinations were made by Mr. G. H. Baston, of the Bureau of Plant Industry, using phenolphthalein as an indicator, after boiling off the carbon dioxid.

It is also well known to farmers that, after a few years' preliminary culture in rye, potatoes, and buckwheat, virgin timberland with its humus-laden soil of a century's accumulation from rotting leaves and roots will sometimes produce heavy crops of timothy, wheat, and clover for one or two generations. The success of these crops shows that the soil has ceased to be acid. Again, when the store of humus derived from the forest has finally been exhausted after long years of ceaseless cropping, these soils revert to a condition of acidity, when lime is regarded as necessary to further agricultural prosperity.

What is this peculiarity of forest leaves by which they make the soil at one time acid, at another alkaline? It is worth while to consider this question, for its answer will throw new light on the practice of agriculture.

DECOMPOSITION OF LEAVES.

A layer of freshly fallen leaves on bare ground, moistened by rain, begins at once to decompose. A brown liquid leaches out of the leaves into the underlying soil. This liquid is acid. If the soil itself is naturally acid, its acidity is increased by these leachings. If the soil is sand, neutral in chemical reaction, it is made acid by the leachings from the leaves. But if the soil is alkaline from the presence of carbonate of lime, as in the case of ordinary loam of high fertility, the acidity of the leaf water is neutralized and its brown matter is precipitated, forming a portion of the black humus of the soil. On such an alkaline soil leaves decay rapidly from beneath and form a black, mellow, and very fertile leaf mold in which all traces of leaf structure have disappeared. Under such conditions the layer of leaf litter is always thin, often not lasting through the summer, and the transition from leaves to underlying mold is abrupt.

In sand, however, there is no such acid-neutralizing substance, and both soil and leaves remain in an acid condition unfavorable to complete decay. The next year a fresh fall of leaves brings a new accession of acidity, and the acid condition of the leaf litter becomes permanent. In a sandy oak or pine woods there is thus built up a tough mat of upland peat often several inches in thickness, composed of half-rotted leaves interlaced with the rootlets of trees and underbrush. Such peat mats are always acid, like ordinary bog peat.

One might conclude from what has been said that leaves unless treated with lime would remain acid throughout the process of decomposition. Such a conclusion, however, would be erroneous. Leaves when sufficiently decayed lose their acidity and of themselves produce a black mold that is not merely neutral in reaction, but sometimes markedly alkaline.

CHANGE FROM ACIDITY TO ALKALINITY.

The reason for this change from acidity to alkalinity lies primarily in the chemical composition of the leaves. From the beginning they are heavily charged with lime, as the following determinations in Table II will show:[1]

TABLE II.—*Percentage of lime in freshly fallen leaves, in terms of calcium carbonate, or ground limestone.*

Kind of leaves.	Percentage of lime.	Kind of leaves.	Percentage of lime.
White oak	1.12	Sugar maple	4.56
Red oak	3.08	Tulip tree	5.06
Silver maple	3.31	Virginia pine	.16

Soils containing such high percentages of lime as these leaves would be markedly alkaline, yet the leaves, as shown by the table on page 2, are strongly acid. It is evident from a consideration of both facts that the lime existing in the fresh leaves has gone into combination with their acid substances to the full extent of its ability to neutralize them, and that the acidity recorded on page 2 represents the acid substances in the leaves in excess of the amount already neutralized by the lime.

As the decomposition of the leaves progresses these excess acid substances are leached out or disorganized, the lime itself is released from its combinations, and a stage is reached where the lime is more than sufficient in amount to neutralize the remaining acidity. The mass has become an alkaline leaf mold. This change from acidity to alkalinity is often hastened by the development through bacteria of ammonia or other substances having an alkaline reaction.

The rapidity with which different kinds of leaves pass from the acid to the alkaline stage varies exceedingly. Leaves of silver maple in some tests have rotted so rapidly as to reach the alkaline state within a year. Red-oak leaves remain acid for several years, and pine leaves for many years.

ACIDITY OF GREEN MANURES.

Acidity determinations of several of the plants that are commonly plowed under for green manure give the following results, expressed in the weight of ground limestone that would be required per acre to neutralize a compact layer 6 inches in thickness.

[1] These lime determinations were made by Mr. J. F. Breazeale, of the Bureau of Chemistry, from duplicates of the same samples from which the acidity determinations on page 2 were made.

TABLE III.—*Acidity of green-manure crops to the acre, in terms of lime requirement per acre.*

Crop.	Acidity.	Crop.	Acidity.
	Tons.		*Tons.*
Alfalfa	13	Rye	11
Red clover	9	Broom sedge	11
Cowpea	10		

The excessive acidity of these green manures at the time they are first plowed under may be more clearly appreciated when one considers that the application of 2 to 3 tons of ground limestone per acre usually satisfies the requirements of an ordinary acid soil. The initial acidity of these green manures is thus shown to be several times that of an equal bulk of ordinary acid soil. In the process of decomposition, however, green manures, like the leaves already described, tend to pass from an acid to an alkaline state, but at rates which have not yet been determined.

The lime requirement of green manures as given in Table III must not be understood as the amount of lime actually required to neutralize the acidity of a crop of these plants when plowed under. A compact 6-inch layer of green manure would never be used in actual practice, but a much smaller amount, as estimated in Table IV. This table gives the estimated weight of the dry crop per acre, roots as well as tops; the amount of lime in the crop, expressed in terms of ground limestone; and the acidity, in terms of the additional amount of ground limestone required to neutralize the initial acidity.

TABLE IV.—*Weight, lime content, and acidity of green manures to the acre.*

Crop.	Weight.	Lime content.	Acidity, expressed as lime requirement.
	Tons.	*Pounds.*	*Pounds.*
Alfalfa	2½	139	267
Red clover	2	131	142
Cowpea	2½	92	200
Rye	2	11	178
Broom sedge	1	4	89

INJURIOUS EFFECTS OF ACIDITY.

Although science can not be said to have demonstrated the full details of the various ways in which ordinary crops are injured by soil acidity, there is known to be one important chemical process which is suspended under acid conditions, namely, the transformation of "unavailable" nitrogen into the form of nitrates. The nitrifying bacteria do not thrive in acid media. In consequence, those crops that require their nitrogen in the form of nitrates suffer

from nitrogen starvation when growing in acid humus. For such crops the neutralization of the acidity by lime is of vital importance, for not until this is done can the nitrogen of the humus, however abundant, be changed into nitrates. Whatever other direct injurious effect acidity may have on crops, the fact that it checks the nitrification of humus is of itself sufficiently important and significant to justify all the investigation that the subject has received.

SOURCE OF NITROGEN FOR ACID-LAND PLANTS.

There is another phase of the acidity question. Many plants thrive in soils which are acid and which therefore theoretically can produce no nitrates. There are three possible methods by which these plants may secure their nitrogen:

(1) Although a sample of soil when tested as a whole shows an acid reaction, there may exist in it innumerable minute tracts, surrounding particles of lime, where the reaction is alkaline and where nitrates are in process of manufacture. It is to be hoped that investigators will find some means to determine the possibility of such a method of nitrogen nutrition in acid soils.

(2) Many acid soils contain a large amount of nitrogen in the form of ammonia, and while hitherto scientific opinion has been much divided over the question whether ordinary crop plants can utilize ammonia nitrogen directly, without transformation by bacteria into nitrates, careful chemical investigation under such conditions as to eliminate the possibility of bacterial action should enable us to determine which of our crop plants can feed on ammonia nitrogen and which can not. Intelligent agriculture needs this information.

(3) It is conceivable that a crop plant might utilize nitrogen that existed in organic form in the humus of the soil, having not yet reached the ammonia stage of decomposition. It is agreed by plant physiologists that ordinary plants, those bearing green foliage, are unable to do this. It is also agreed by plant physiologists that fungi not only can but habitually do use organic nitrogen. These two facts warrant the consideration of a remarkable partnership that exists between certain leaf-bearing plants and certain fungi, a partnership the significance of which has only recently begun to be appreciated by botanists and is almost unknown in agricultural literature.

The subject is well illustrated in the blueberry. The possibility of the culture of this wild berry has been under investigation for several years, the experiments having now reached a successful conclusion.[1]

[1] Experiments in Blueberry Culture, United States Department of Agriculture, Bureau of Plant Industry, Bulletin 193, 1910; also Directions for Blueberry Culture, United States Department of Agriculture, Bureau of Plant Industry, Circular 122, pages 3 to 11, 1913.

THE MYCORHIZAL FUNGI.

It has been found that the blueberry requires an acid soil, that it grows luxuriantly in a mixture of peat and sand containing nitrates in extremely minute quantities, if, indeed, they are present at all. The plant bears upon its roots a fungus the microscopic threads of which lie partly on the outside of the root, but penetrate also into the living interior. While the experimental results can not as yet be regarded as furnishing an absolute proof, the evidence strongly indicates that the fungus takes up organic nitrogen from the abundant supply existing in the peat and delivers it to the plant in some available form.

These mycorhizal fungi exist on the roots of many wild plants inhabiting acid peat. The extent to which they occur on the roots of cultivated plants that grow in acid soil is not yet known. It can hardly be doubted, however, that many such plants will ultimately be found to take their nitrogen through these fungi. Other acid-land plants will doubtless be found to possess the ability to use nitrogen in the form of ammonia without the help of fungi.

This outline of the probable means of nitrogen assimilation in acid-land plants prepares the way for the following survey of crops adapted to acid soils.

CROPS ADAPTED TO ACID SOILS.

BLUEBERRY.

The blueberry, to which allusion has already been made, gives every indication of adaptability to commercial culture, now that its soil requirements and its peculiarities of nutrition are known. The establishment of a blueberry-growing industry will mean the utilization of sandy, acid lands in the pine barrens of New Jersey and similar situations now regarded as almost useless agriculturally.

CRANBERRY.

The cranberry is an acid-land fruit. It has a root fungus similar to that of the blueberry and doubtless of the same importance to the welfare of the plant. The lands used for cranberry culture are of a special kind, with such an excess of moisture and acidity that in comparatively few instances would they have been used for any other agricultural purpose.

STRAWBERRY.

The strawberry is now coming to be recognized as a plant that thrives as well, if not a little better, in soils having an acid reaction. The grower who appreciates this characteristic of the strawberry is relieved of the expense of applying lime to his land unless required by other plants in his crop rotation.

BLACKBERRY, RASPBERRY, AND BLACKCAP.

The blackberry, the American red raspberry, and the blackcap are found wild in acid soils and all thrive in cultivation in such land if the ground is well supplied with humus.

POTATO.

The potato has long been recognized as yielding especially well when grown on a newly turned sod or on newly cleared land, conditions which are now recognized as productive of acidity as well as a later increase of humus. The potato, moreover, furnishes one phenomenon of special interest to acid-land agriculture. The potato scab, a disease which reduces the size of the tubers, injures their appearance, and lessens their value, is controlled without difficulty if the soil reaction is acid. The disease is caused by a fungus known as *Oospora scabies*, the growth of which is inhibited by acidity.

SWEET POTATO.

The sweet potato, the cultivation of which extends as far north as New Jersey, yields heavily in acid soils. In the South it is the standard vegetable on such lands.

RYE.

Rye is a cereal that grows almost as well on acid as on nonacid soils. It is the characteristic grain on the reclaimed acid heather lands of northern Europe. In the United States it is found particularly useful as a cover crop on areas subject to washing in winter, whether the rye is later cut for hay, or plowed under for green manure, or harvested for its grain.

OATS.

As a grain for spring sowing, oats do well in acid soils, though this crop is not so acid tolerant as millet. It is often useful in rotations where the crop of the preceding summer can not be harvested early enough to permit the successful sowing of a winter cover crop like rye.

MILLET.

The different varieties of foxtail millet, including common millet, German millet, and Hungarian millet, are strongly acid tolerant. As they are also drought resistant and reach maturity in a remarkably short period, they are useful for summer sowing in land temporarily vacant between the more important crops of a rotation.

BUCKWHEAT.

Buckwheat is well known as a pioneer crop on newly cleared timberland. Its reputation also as a crop for worn-out lands is another

indication of its resistance to acidity, for such lands are usually acid. If, however, the mineral food is actually insufficient and there is no humus from which nitrogen can be extracted, one can not reasonably expect a heavy yield, even from buckwheat. The plant can withstand acidity, but not starvation besides. A reasonable amount of humus, such as is easily provided by plowing under a good leguminous crop, will ordinarily result in heavy yields of buckwheat.

REDTOP.

The principal grasses of ordinary agriculture, notably bluegrass and timothy, do poorly in acid land. To this general rule, however, there is one notable exception, redtop. This grass often reaches a luxuriant development in markedly acid lands. The stem growth of redtop, however, is so light compared with that of timothy that it is not recommended as a substitute so far as the production of hay is concerned, but, like bluegrass, its bottom growth is heavy and it makes an excellent pasture.

CORN.

Corn yields well under acid conditions if the soil is well provided with humus and the usual mineral nutrients. It may be regarded as a plant having a fair degree of acid tolerance.

CARROT.

The carrot, as might readily be inferred from its common occurrence as a weed in old and worn-out fields, is decidedly tolerant of acidity. It grows almost equally well in either type of soil.

TURNIP.

The common turnip produces good though probably not maximum yields on acid land, differing in this respect from the rutabaga, or Swedish turnip, which yields well only in neutral or alkaline soils.

LEGUMINOUS PLANTS FOR ACID SOILS.

While the crop plants thus far enumerated furnish material for such agricultural necessities as grain, grain hay, fodder, root crops, cover crops, pasturage, and small fruits, they do not supply the nitrogenous green manures which are necessary to the maintenance of soil fertility under most agricultural conditions and which are satisfactorily derived only from leguminous plants. It is admitted that in acid-land agriculture red clover, the ordinary green-manure crop, is not available for this purpose. What, then, are the leguminous plants which will produce in an acid soil a heavy growth of tops equal in value to red clover for plowing under as green manure? The answer is, cowpea and hairy vetch. Crimson clover, soy bean, lupine, and serradella are also useful under certain conditions.

COWPEA.

For a century the cowpea, of many varieties, has been the chief leguminous crop of the Southern States, grown for hay, for its edible seeds, and as a green manure. Only recently has its resistance to acidity been recognized. The experiment stations have carried the plant much farther north in the past few years, until now some of the varieties are in successful cultivation in Massachusetts, New York, and Michigan. Sometimes the yield of tops is so dense and heavy that only by the use of special attachments to the plow can the crop be turned under.

SOY BEAN.

The soy bean is of much more recent introduction into the United States than the cowpea. In its tolerance of acidity the soy bean probably equals the cowpea, and it has two points of superiority. It grows farther north and its yield of seed is much greater, often being as high as 30 bushels per acre. Some of the varieties have been grown with success as far north as New Hampshire, Ontario, and Wisconsin. The seed of the soy bean has one remarkable characteristic. It contains no starch, but about 35 per cent of nitrogenous matter. Such a composition ought to give these beans a special value in rations for cattle. Within the climatic limits of its profitable cultivation this plant may prove to be exceedingly valuable on the acid dairy farms of New England, where enormous sums are spent for the purchase of southern and western nitrogenous cattle feeds.

HAIRY VETCH.

Hairy vetch differs in one conspicuous feature from the cowpea and soy bean. Both these plants are sown in the spring or early summer and mature and die in the fall of the same year, but the hairy vetch is what is known as a winter annual. It is sown in late summer, germinates at once, passes the winter as a small plant, makes a heavy growth in the following spring, and matures its seed in early summer. It so closely accords in season with rye that the two form an ideal mixture when the rye is to be plowed under for green manure or cut for early hay.

CRIMSON CLOVER.

Crimson clover is a leguminous plant that does well in sandy soils from New Jersey southward. It appears to be tolerant of acidity and may come to be definitely recognized as a plant of this class. The seed is sown in late summer, becomes well established before winter, makes a luxuriant growth in early spring, and is ready for the scythe or the plow in May.

Further experimentation will doubtless result in important additions to this list. It is especially desirable that additional leguminous plants be found that are hardy far north and otherwise satisfactory in rotations. Lupine and serradella, both much employed in the great potato-growing districts of Pomerania and other portions of north Germany, ought to be useful in this country, but thus far they have not found favor, perhaps because of the poisonous qualities of lupine and the rather light yield of serradella.

ACID-TOLERANT CROPS IN ROTATION.

From the data already given, the farmer who desires to try an experiment in acid-land agriculture will be able to select the crops that will give him the rotation suited to the requirements of the particular kind of agriculture in which he is engaged. Some of these crop plants are comparatively new and require special handling as to the best time and manner of sowing. When grown for the first time the leguminous plants require soil inoculation with the special bacteria of their root tubercles.

Rotations made up from the acid-tolerant crops described above have been very successful on some of the sandy, acid farms in Maryland, a few miles northeast of Washington.

The trees in one newly planted orchard of Grimes Golden apples have been kept in a remarkable condition of growth by one initial application of manure in the year of their planting, succeeded by the following rotation: In May the ground is sowed to cowpeas. These are plowed under in September and followed immediately by the sowing of rye mixed with hairy vetch. In the following May the mixed crop is plowed under. The same one-year rotation has been followed year after year. Under this treatment the soil, which has the appearance of almost pure sand, has become so fertile without the application of lime, commercial fertilizer, or manure that an occasional crop of cowpeas has been cut for hay without serious interference with the progress of the orchard.

Another successful combination is a one-year rotation of corn and crimson clover by which a heavy yield of corn is produced every year without lime or fertilizer in a soil that looks almost like beach sand. The land, which is gently sloping, is ridged in contours at each interval of 2 feet in elevation, the corn rows being parallel to the contour next above them. The crop of crimson clover with the corn stubble is plowed under in April a little before corn-planting time. In August after the last cultivation of the corn the crimson clover is sown between the rows. The seeds germinate so readily that when broadcasted a light shower will start them off. If dry weather follows before they have had time to send their roots deep

enough to reach the permanently moist soil beneath the dry surface layer, the young plants promptly die. It is safer, therefore, either to sow the seed with a drill or to broadcast it during a heavy rain, which will beat the seed into the ground and at the same time furnish sufficient moisture to carry the young plants through the period of danger from drought.

The turning under of heavy leguminous crops on these sandy soils restocks the land with humus and the humus decomposes to such a stage that a condition of partial or temporary alkalinity appears at times to have been reached, for good crops of even such nonacid plants as wheat and timothy are sometimes secured from these naturally acid lands after the treatment here described.

BENEFICIAL EFFECTS OF SOIL ACIDITY.

An actual beneficial effect from soil acidity is likely to be felt in another direction hitherto insufficiently recognized, namely, the control of some of the fungous diseases of cultivated plants. Reference has already been made (p. 8) to the fact that the fungus causing the scab of the potato can not grow if the soil reaction is acid. Another example is furnished by the root-rot of the tobacco plant, caused by a fungus named *Thielavia basicola*. Briggs has shown that this disease is prevalent in tobacco plantations that have received excessive applications of lime or other alkaline fertilizers and that it is readily controlled by the use of acid fertilizers.

In Porto Rico the extension of the pineapple industry has been retarded by a disease known as chlorosis, the principal external mark of which is the yellowing of the foliage and the consequent poor nutrition of the plant. From investigations by Gile and by Loew it appears that the yellow color of the leaves and the accompanying weakness of the plant are due to the lack of iron, and that where the soil contains an excess of lime the organic acids which are needed to dissolve the iron of the soil are themselves neutralized and the iron, although present, is not available for absorption by the pineapple roots.

In the upbuilding of the agriculture of the arid Western States certain diseases of plants have appeared which are commonly called by plant physiologists cases of "malnutrition." The causes of these maladies are unknown. The maladies themselves, however, are associated with pronounced alkalinity of the soil and they occur in plants that were native in humid regions where the soil varies from weak alkalinity to actual acidity. May it not be worth while for investigators to ascertain whether some of these mysterious "malnutrition" difficulties can not be remedied by an acid treatment of the soil?

There is one other feature of the acid-soil question which merits the serious consideration of agriculturists. Recent investigators have shown that various fungi are able to fix and feed upon the nitrogen of the atmosphere, just as do the bacteria of the clover root tubercles and certain free bacteria of alkaline and neutral soils. One Swiss investigator, Charlotte Ternetz, has isolated from acid soils several fungi in which this faculty not only occurs but is developed to a high degree of efficiency. It has not yet been fully demonstrated that true mycorhizal fungi possess this faculty of nitrogen fixation, but there is much evidence that they do. Should this become definitely established, agriculture must recognize in the mycorhizal fungi a direct and powerful means of adding to the store of available nitrogen, and the culture of mycorhizal plants in acid soils will have a significance far beyond the mere value of the crops produced by them.

CONCLUSION.

In closing this paper the writer desires to impress on agricultural investigators (1) that soil acidity is not always an objectionable condition which invariably requires an application of lime, (2) that under certain economic conditions a complete system of acid-land agriculture is practicable and desirable, and (3) that the extent to which our cheap eastern acid lands can be utilized with small applications of lime, or under some conditions without its use, is a legitimate and important subject for detailed investigation, from which may reasonably be expected results of far-reaching economic importance.

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